NRL Report 7046

Fracture Toughness of Structural Metals

E. A. Lange

Strength of Metals Branch
Metallurgy Division

May 4, 1970

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amount of stretch that occurs prior to fracture. Since the operative microfracture modes are related to the basic microstructure, impurities, and processing conditions, brief discussions of this aspect are considered in the following sections for the more important structural metals.

Carbon and Low-Alloy Steels

Conventional structural and pressure-vessel steels, which represent the major tonnage of materials for all engineering applications, have a low alloy content and therefore low hardenability. In general, they have pearlitic microstructures after the usual air cooling from high temperatures, following a forming operation or a normalizing heat treatment. Two very contrasting microfracture modes are possible in these materials, cleavage and microvoid coalescence. Examples of these two extremes in metal separation are illustrated by the microfractographs shown in Fig. 3. These microfracture modes are readily distinguishable even without magnification because the flat facets of cleavage fracture provide a high reflectivity and bright appearance, whereas the dimpled surface from microvoid coalescence provides an absorptive surface and dull appearance.

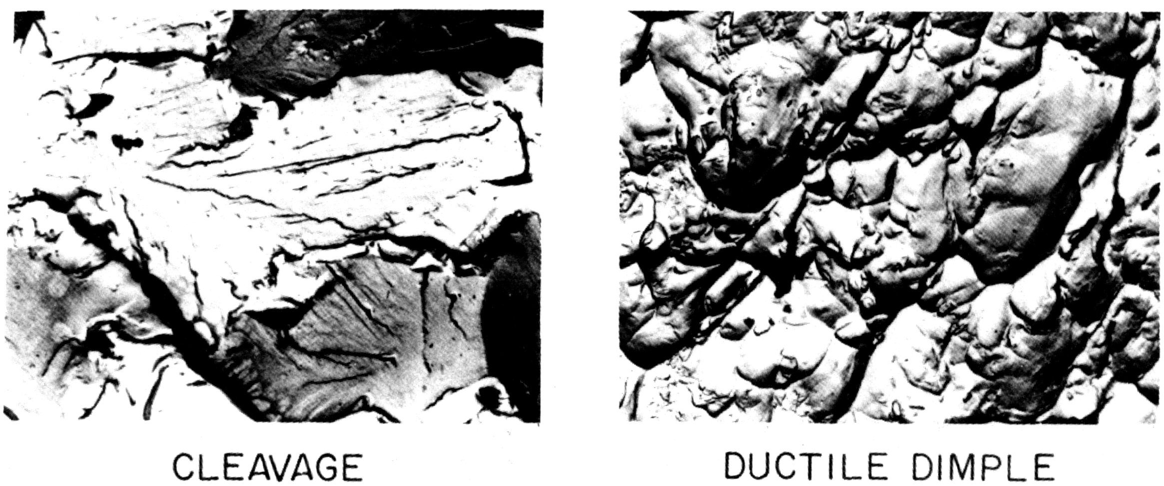

Fig. 3 - Electron microscope fractographs illustrating the two microfracture modes of carbon and low-alloy steels with pearlitic microstructures: (left) cleavage, a brittle mode; (right) microvoid coalescence, a ductile mode. Approximately 4000X.

Cleavage fracture occurs when a critical level of stress is reached, and this fracture mechanism approaches a true tensile or opening mode type of separation (4, 5). Any condition that results in an increase in yield stress, such as decreasing temperature, increasing triaxiality, and increasing strain rate, will favor cleavage fracture. Although some strain hardening may be required to initiate cleavage fracture, once started, cleavage fractures propagate at high rates of speed because very little plasticity or energy is associated with the propagation of this type of fracture, and elastic strain energy can drive the crack.

When mechanical and thermal conditions in conventional pearlitic steels are such that through-section yielding occurs and cleavage fracture stress can no longer be attained even with high strain rates and strain hardening, fracture occurs by microvoid coalescence. The amount of plasticity that precedes total separation when this ductile

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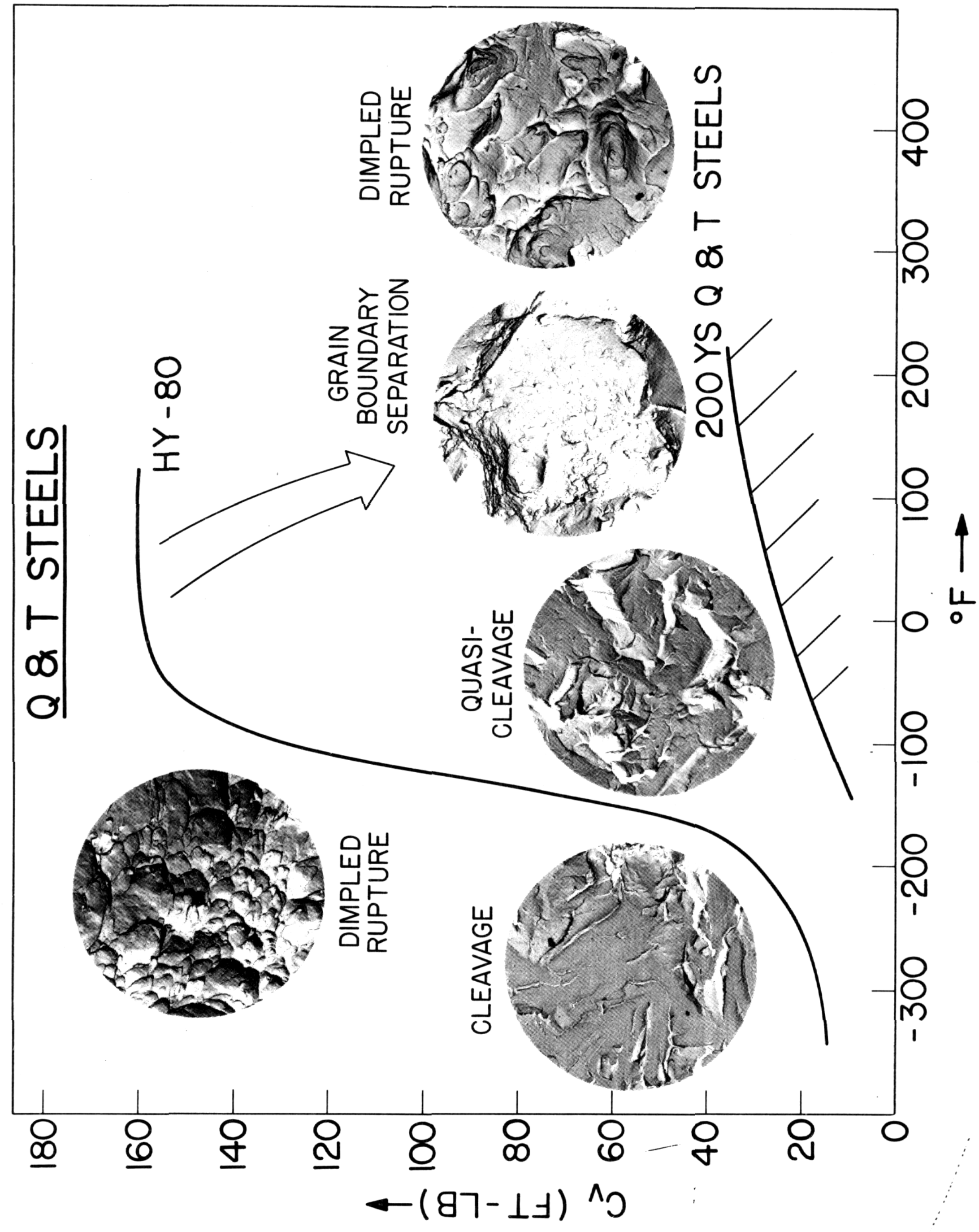

Fig. 4 - Microfracture mechanisms of high-strength steels in relation to C_v curves. Approximately 4000X.

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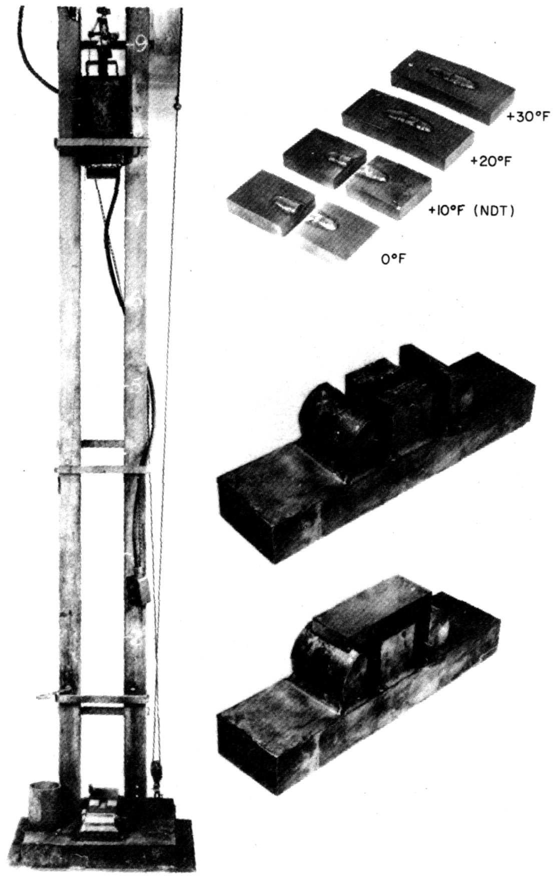

Fig. 5 - Drop-Weight-Test (DWT) equipment and DWT series illustrating the sharp increase in dynamic fracture toughness above the NDT temperature

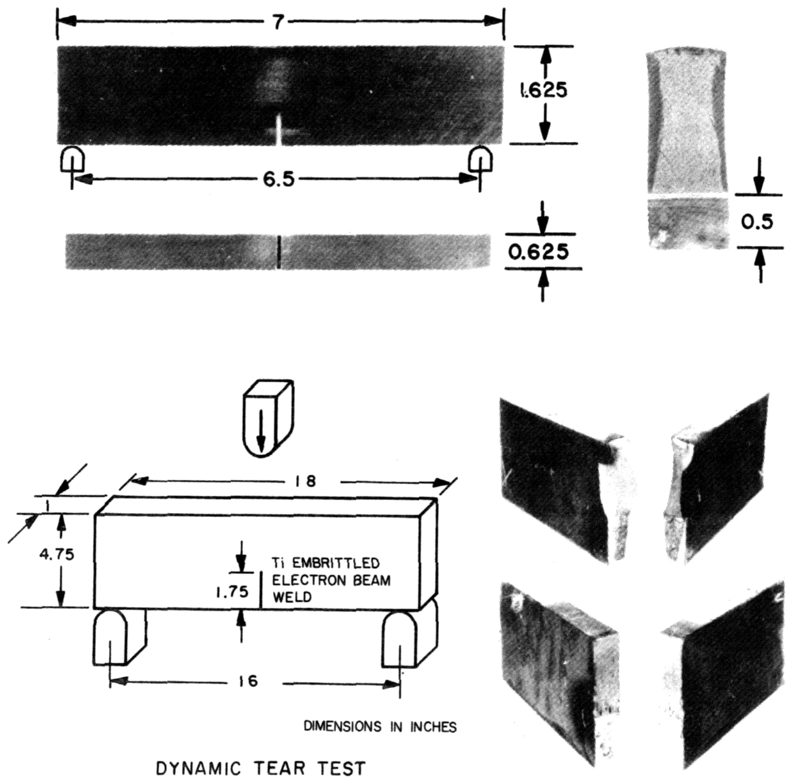

Fig. 6 - Features of 5/8-in. and 1-in. DT test specimens. The 5/8-in. DT specimen (top) features a machine slit with a knife-edge-sharpened notch tip. The 1-in. DT specimen (bottom) features a brittle electron beam weld, which is also used for the 5/8-in. DT, as desired. The broken halves of the 1-in. DT specimens illustrate brittle and ductile type fractures.

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